REPORT M-7
SOILS INVESTIGATION

PROPOSED AMMONIA PLANT
EAST DUBUQUE, ILLINOIS

FOR THE
NORTHERN ILLINOIS GAS COMPANY

DAMES & MOORE

CONSULTANTS IN APPLIED EARTH SCIENCES

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ASSOCIATES: ROBERT M. PERRY · JOSEPH A. FISCHER

September 15, 1964

The Lummus Company
146 Haynes Avenue
Newark, New Jersey

Attention: Mr. D. E. Costello

Gentlemen:

We submit herewith ten copies of our "Report, Soils Investigation, Proposed Ammonia Plant, East Dubuque, Illinois, for the Northern Illinois Gas Company".

The scope of the investigation was planned in cooperation with representatives of The Lummus Company. Preliminary conclusions regarding site preparation and foundation requirements were transmitted verbally to engineers of The Lummus Company during the course of the work in order to expedite preliminary planning and design.

The results of our investigation indicate that the site is suitable, from a foundation standpoint, for development by the construction of the proposed Ammonia Plant. Considerable earthwork is necessary in order to attain the desired final grades. We believe that pile foundations will not be required in fill areas provided that all fill is properly placed and compacted under the constant supervision of qualified engineering personnel. More detailed foundation analyses and, possibly, additional field explorations should be performed when the locations of all important structures have been definitely established.

Yours very truly,

DAMES & MOORE

Robert M. Perry

Robert M. Perry

RMP ED

CABLE ADDRESS DAMEMORE

REPORT

SOILS INVESTIGATION

PROPOSED AMMONIA PLANT

EAST DUBUQUE, ILLINOIS

FOR THE

NORTHERN ILLINOIS GAS COMPANY

INTRODUCTION

GENERAL

This report presents the results of a soils investigation performed at a site near East Dubuque, Illinois, which may be developed by the construction of a proposed ammonia plant for the Northern Illinois Gas Company. The location of the site is indicated on the Map of Area, Plate 1, with respect to the nearby Mississippi River and other prominent local topographical and cultural features.

The site under consideration is one of four initially explored* sites in this area. This site has been selected for the proposed plant because, among other factors, it appeared to possess the most favorable soil conditions of the four initially explored sites.

DESIGN CONSIDERATIONS

It is understood that the initial proposed facilities will include: two ammonia storage tanks; an administration building; and a

* See our "Report of Consultation, Proposed Chemical Plant Complex, East Dubuque, Illinois, Northern Illinois Gas Company", dated May 12, 1964.

process area which will include compressors housed in a compressor building; a heater unit; a control house· heat exchangers and pressure vessels and tanks, A water treating unit, a maintenance shop and warehouse, and a cooling tower and basin will be located near the process area. Truck liquid loading and railroad facilities also will be provided.

We understand that the final locations for all the structures have not been determined. It is presently planned to locate the ammonia storage tanks near the area where Borings BP-104 and BP-107 were drilled. The process area and surrounding units will be located in the general area where Borings BP-103 and BP-111 were drilled. The administration area will be located in the vicinity where Boring BP-101 was drilled.

We have been informed that the two ammonia storage tanks will be double-walled insulated units. One of the tanks will have an outside diameter of 146 feet and be approximately 62 feet high. The second tank will be approximately 142 feet in outside diameter and on the order of 64 feet in height. It is understood that the tanks will be constructed with cone roofs. The stored liquid ammonia will have a density of approximately 43 pounds per cubic foot.

It is presently planned to establish the final grade in the process area at Elevation +734. The final grade in the administration building area will be higher than in the process area, and has been tentatively established at approximately Elevation +750. It is planned to locate the ammonia storage tanks at Elevation +720 feet. In order to attain these desired grades, as much as 25 feet of cut and 20 feet of fill will be required.

PURPOSE

The purpose of this investigation was to:

1) explore the soil and ground water conditions underlying the site;

2) recommend the more suitable areas of the site, from a foundation standpoint, in which to locate major plant units;

3) present recommendations for site preparation;

4) recommend suitable types of foundations to support the proposed structures and present general design criteria for these foundations; and

5) present other recommendations or suggestions which might facilitate site development and foundation design and installation.

SCOPE OF WORK

In order to accomplish our investigation, a program was conducted which included field explorations, laboratory testing and engineering analyses.

The soil and ground water conditions at the site were explored by drilling a total of eleven test borings to depths between 46 and 82 feet below the ground surface. The locations of the borings are shown on Plate 2, Plot Plan.

The field explorations were conducted under the technical direction of a Dames & Moore Soils Engineer. Undisturbed soil samples, suitable for laboratory testing, were extracted from the borings and flown to our New York office for examination and testing. The physical properties of the various soil strata were determined from results of tests performed on selected samples.

More detailed descriptions of the field explorations and laboratory tests, which provide the basis for our engineering analyses and recommendations, are presented in the Appendix to this report. We have presented in this report sufficient recommendations and criteria for site planning, site preparation and preliminary foundation design. The development of design criteria for specific structures was beyond the scope of this present investigation.

SITE CONDITIONS

GENERAL GEOLOGIC HISTORY

The site is located in the Driftless Section of the Central Lowlands Physiographic Province of North America. The Driftless Section occupies an area including parts of Wisconsin, Illinois, Iowa and Minnesota, and is entirely surrounded by glacial drift-covered country. During glacial times, several stages of glaciation carried ice sheets far to the south of this area; however, the ice wrapped completely around the Driftless area without overriding it. The ice sheet was formed mainly of two large lobes which followed the lowlands of Lake Michigan and Lake Superior.

The Driftless area of Illinois is essentially the area occupied by a broad, much-dissected cuesta or sloping plain, which is terminated on one side by a steep slope. The cuesta is composed of dolomite and/or limestone of Ordovician Age. These rocks are resistant and dip gently southwestward. The cuesta face trends generally southeastward. The low dip of the cuesta-forming layer fails to carry it beneath the flood plains of the Mississippi River; consequently, it is trenched by the River and cut into high, almost vertical, cliffs.

Large volumes of silt were blown in from the surrounding drift areas during the several stages of glaciation onto the uplands bordering the valleys to form extensive deposits of loess. Thick deposits of loess exist in the site area which somewhat conceal the features of the cuesta underlying them. The loess deposits are generally thicker on the bluffs and high grounds than away from them.

Thick deposits of sand also occur in the site area, overlying the loess. The origin of the sand is uncertain; it could be either an alluvial deposit or an aeolian deposit resulting from high-velocity winds.

SURFACE FEATURES

The site is located northeast of the Mississippi River, and slightly inland. In this area, the terrain is undulating, but generally slopes upwards from the River towards the northeast. The elevation of the area explored ranges from a minimum of approximately +710 near the southern boundary to a maximum of approximately +800 in the northeast corner.

At the time of the field explorations, the area was being used as pasture land. A heavy growth of grass with occasional shrubs, approximately two to three feet high, covered the area. Isolated trees were also growing in the area. Several farm houses and related structures were located just outside of the area investigated.

SUBSURFACE CONDITIONS

The borings indicated that the site is underlain, in general, by:

1) a limited depth of surface soils consisting of varying thicknesses of relatively clean sand, silty and clayey sand, silt and clayey silt;

2) an intermediate stratum consisting predominantly of moderately compact sandy soils;

3) a lower stratum of silty soil; and

4) limestone bedrock

The "surface soils" were observed to range in depth from one foot to nine feet at the boring locations. A topsoil cover, consisting of brown silty sand, silty clayey sand, or clayey silt, with roots, was observed to depths on the order of one foot. Varying thicknesses of silty sand, silt, and clayey silt underlie the topsoil to depths of up to nine feet below the ground surface. These soils generally were firm or compact.

Moderately compact brown fine sand, fine to medium sand or silty sand was encountered below the soils described above. The thickness of this sandy stratum was observed to vary between 15 feet and 38 feet, except at the locations of Borings BP-104 and BP-111, where only five feet of sandy soil was encountered.

Silty soils were encountered below the sand at depths ranging from 14 feet to 48 feet below the ground surface. In general, these soils were moderately firm. However, in the southern area (plant south) of the site, in the vicinity of Borings BP-104, BP-105 and BP-106, the silty soils below Elevation +690 feet were observed to be loose and compressible. A limited thickness of moderately compressible soil was also encountered below Elevation +680 at the location of Boring BP-109.

A thin stratum of sand mixed with gravel and rock fragments generally was encountered below the silty stratum and immediately above the bedrock. The sand and gravel stratum was observed to have a maximum thickness of about five feet.

At the boring locations, refusal to further penetration of the drilling equipment was encountered at depths ranging from 46 feet to 82 feet below the ground surface. It is assumed that this refusal was encountered on the limestone bedrock believed to underlie the area. The rock was not cored.

The ground water level was recorded at the time of our field explorations at depths varying between 37 feet and 44 feet below the ground surface.

More detailed descriptions of the soils encountered in the borings are shown on the Log of Borings presented in the Appendix to this report.

DISCUSSION AND RECOMMENDATIONS

GENERAL

In order to locate the proposed facilities at the desired elevations, considerable earth cut and fill will be required in certain areas. The field explorations have indicated that relatively firm or compact sands and silts underlie the northern (plant north) portion of the site. In the southern area, highly compressible silt was encountered at depths of 20 to 30 feet below the existing ground surface. When this condition became evident during the field explorations, a decision was made to move the proposed plant area to the higher northern ground, away from the southern area.

Based upon a review of the subsurface conditions and general design features of the proposed plant, it is our opinion that:

1) the on-site sand underlying the surface soils can be satisfactorily utilized as structural fill in areas where the existing grade is lower than final grade;

2) the proposed structures can be supported on spread or mat foundations installed on the natural soils or on properly placed and compacted sand fill;

3) all heavy structures and structures that would be adversely affected by settlement should be located in the northern (plant north) and central portions of the area investigated which are not underlain by highly compressible soils; and

4) the ammonia storage tanks can be supported at the planned location without the use of pile foundations, provided that some settlement is tolerable.

More detailed discussion of site preparation and foundation requirements are presented in the following sections of this report.

SITE PREPARATION

Prior to grading operations, it is recommended that the topsoil containing roots be stripped from both the cut and fill areas. The fill areas at the locations of proposed structures should be "proof-rolled" with heavy equipment to determine if zones or pockets of soft soils exist near the surface. Any soft soils observed should be recompacted or excavated and replaced with suitable material.

It is our opinion that the sand underlying the surface soils can be satisfactorily used for compacted fill. The fill could be utilized for support of structures if it is placed and compacted under properly controlled conditions. The surface clayey silt and sandy silt obtained from the cut areas should be used as fill in areas where structures will not be located or this soil should be wasted if the quantity of cut exceeds the required fill.

It is recommended that the fill be placed under the direction of a qualified soils engineer. The fill should be placed in layers approximately six inches in thickness and compacted to a density of at least 95 percent of the maximum density obtainable by the Modified AASHO*Method of Compaction.

The results of a compaction test performed on a sample of the brown fine to medium sand obtained at the location of Boring BP-107 is presented in the Appendix. The field moisture content of the sand in most portions of the site compares favorably with the optimum moisture content determined by the compaction test. However, it should be recognized that the moisture content of the sand will vary with both location on the site and the season of the year. Consequently, it may be necessary to add water to the soil from some areas in order to achieve satisfactory compaction, particularly if earth-moving operations are conducted during or after dry weather.

The characteristics of the sandy soil were observed to vary somewhat at different locations of the site. It is recommended that additional compaction tests be performed in the field on materials encountered at differing locations in order to make certain that the soils obtained from these areas are being properly compacted.

Areal settlement of the fill areas will result from the weight imposed by the fill. The estimated magnitude of settlement which will result from various thicknesses of fill is presented on Plate 3, Settlement of Areal Fill. Generally, the greatest amount of settlement is expected to occur in the southern areas of the site which are underlain by more compressible soils. The lower range of settlements indicated on Plate 3

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*American Association of State Highway Officials would be more applicable to the northern and central areas of the site. It is our opinion that approximately three-fourths of the anticipated areal settlement will occur during earth-moving operations. We believe that the remaining settlement will be experienced within a period of a few months. We recommend that settlement plates be installed before filling operations in at least 12 locations in order to provide a field check on the magnitude and rate of areal settlement.

SPREAD AND MAT FOUNDATIONS

It is our opinion that the proposed structures can be supported on spread or mat foundations installed on the existing soils or on structural fill which has been placed and compacted in accordance with the recommendations presented in the previous section on Site Preparation.

We recommend that foundations exposed to frost be installed a minimum of four and one-half feet below final grade. It is our opinion that net bearing pressures between 3,000 and 4,000 pounds per square foot could be used at this site in proportioning the foundations. The final design bearing pressure will depend on the location and the type of structure under consideration.

We believe that properly placed and compacted sand fill will be capable of developing higher soil bearing values, and will provide higher resistance to compression under loading, than the natural soils. It is our opinion that a net bearing pressure of 4,000 pounds per square foot can be used in areas where foundations will be installed on sand fill which extends four feet or more below foundation elevation, provided that the fill has been placed and compacted under the direction of a qualified soils engineer.

The natural soils are moderately firm or compact (except in the southern areas of the site). However, the soil characteristics were observed to vary somewhat at boring locations. When the final location for each major structure is determined, we recommend that settlement analyses be performed in order to make certain that the estimated settlement of the structures will be tolerable. It may be desirable to drill some additional borings at critical locations, inasmuch as the initial field exploration program consisted of relatively widely spaced borings.

COMPRESSORS

Based upon the static loading imposed by the compressors, we believe that these units could be satisfactorily supported on mat foundations and that pile foundations would not be required. However, it would be prudent to perform a dynamic analysis of the soil-foundation system to evaluate the behavior of compressors under operating dynamic loading conditions. If we were informed of the operating characteristics and the final locations of the compressors, we would be able to perform the required dynamic analysis.

AMMONIA STORAGE TANKS

Some earth cut and fill will be required to level the proposed area of the ammonia storage tanks at planned final grade, Elevation +720 feet. Based upon the understanding that the proposed tanks will be relatively flexible and can tolerate differential settlement, it is our opinion that they can be supported at the proposed location without the use of piles provided the tank areas are prepared in accordance with the following recommendations.

1) Topsoil containing roots should be stripped from the areas where the existing grade is below the final grade.

2) The high areas should be cut to a minimum of 18 inches below final grade.

3) The exposed surface should be compacted with heavy rolling equipment. Any soft areas or pockets should be excavated.

4) The area should be raised to final grade with sand fill placed in six-inch layers. Each layer should be compacted to a density of at least 95 percent of the maximum density obtainable by the Modified AASHO Method of Compaction.

5) A crushed rock or well-graded gravel ring wall, three feet wide, should be placed beneath each tank shell. The ring wall should extend to a minimum depth of five feet. The bottom of the ring wall excavation should be inspected to make certain that pockets of soft soils do not underlie the tank shell. Where soft soils are observed, the excavation should be extended until firm soils are encountered.

Due to the fact that the soils underlying the tank area, particularly the deeper silty soils, are somewhat compressible, the tanks will experience some settlement. We estimate that the settlement of the center of each tank will be on the order of five to seven inches and that the settlement of the edge of each tank will be about three to five inches. It is anticipated that approximately one-half to three-fourths of the estimated settlement will occur during the water test period, and the remainder over a period of a few months after the full operating load is applied. We recommend that, if possible, the connection of piping to the tanks be delayed until after the water test period.

DRAINAGE DITCHES

We understand that drainage ditches will be provided for control of rainwater. The maximum depth of these ditches will be on the order of four feet. We believe that slopes of two horizontal to one vertical in the sand and three horizontal to one vertical in the silt will be stable. However, these fine-grained soils are sensitive to erosive forces. Grass or similar cover, or a protective lining of concrete, soil-cement or asphalt would be desirable in order to minimize maintenance of the ditches.

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The following Plates and Appendix are attached and complete this Report:

Plate 1	-	Map of Area
Plate 2	-	Plot Plan
Plate 3	-	Settlement of Areal Fill
Appendix	-	Field Explorations and Laboratory Tests

Respectfully submitted,

DAMES & MOORE

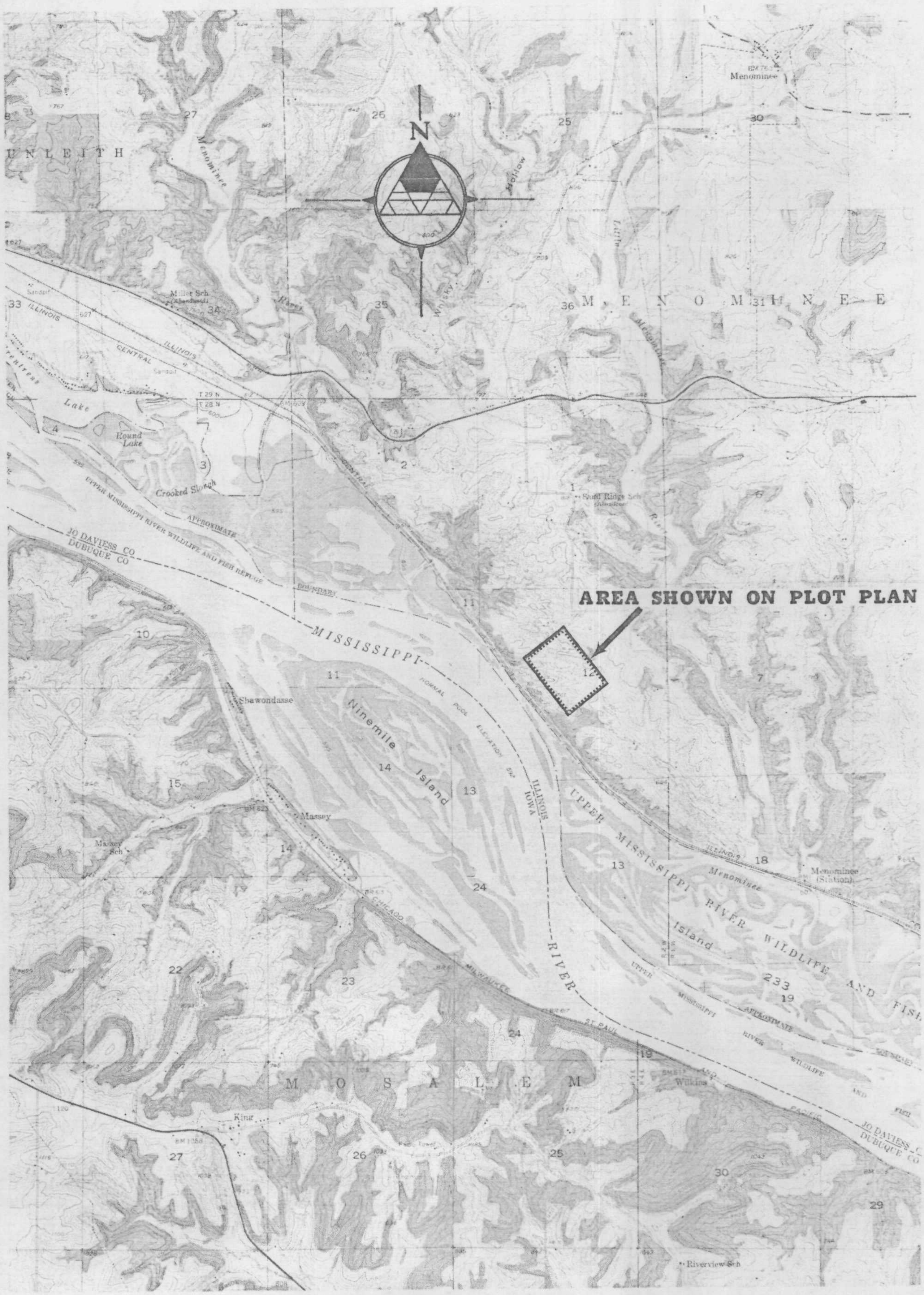
Robert M. Perry

Robert M. Perry

George D. Leal

George D. Leal
P. E. Registration No. 62-21832
State of Illinois

RMP-GDL-DFMcC NC



MAP OF AREA

1 MILE

1000 0 1000 2000 3000 4000 5000 6000 7000 FEET

1 KILOMETER

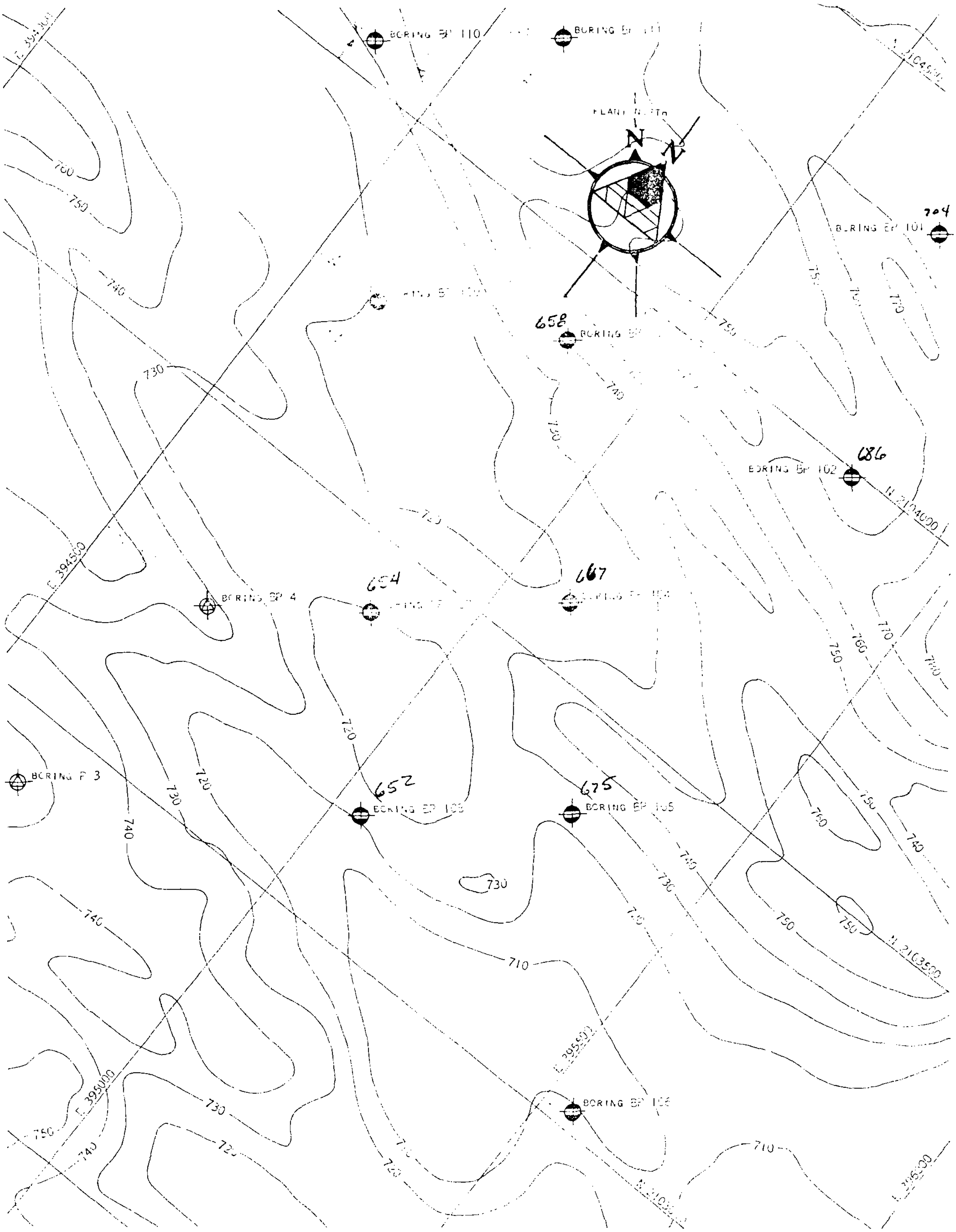
CONTOUR INTERVAL 10 FEET
DOTTED LINES REPRESENT 5-FOOT CONTOURS
DATUM IS MEAN SEA LEVEL

NOTE:

THIS MAP OF AREA WAS PREPARED FROM A PORTION OF USGS MENOMINEE, ILL.-IOWA QUADRANGLE 1955.

DAMES & MOORE
APPLIED EARTH SCIENCES

PLATE I



KEY:

BORINGS DRILLED FOR THIS INVESTIGATION

BORINGS DRILLED PREVIOUSLY BY OTHERS

PLOT PLAN

FEET

100 0 100 200

REFERENCE:

THE LUMMUS COMPANY, DWG. NO. SKE 5396-151-2, DATED 6-25-64, ENTITLED "LOCATION OF TEST BORINGS."

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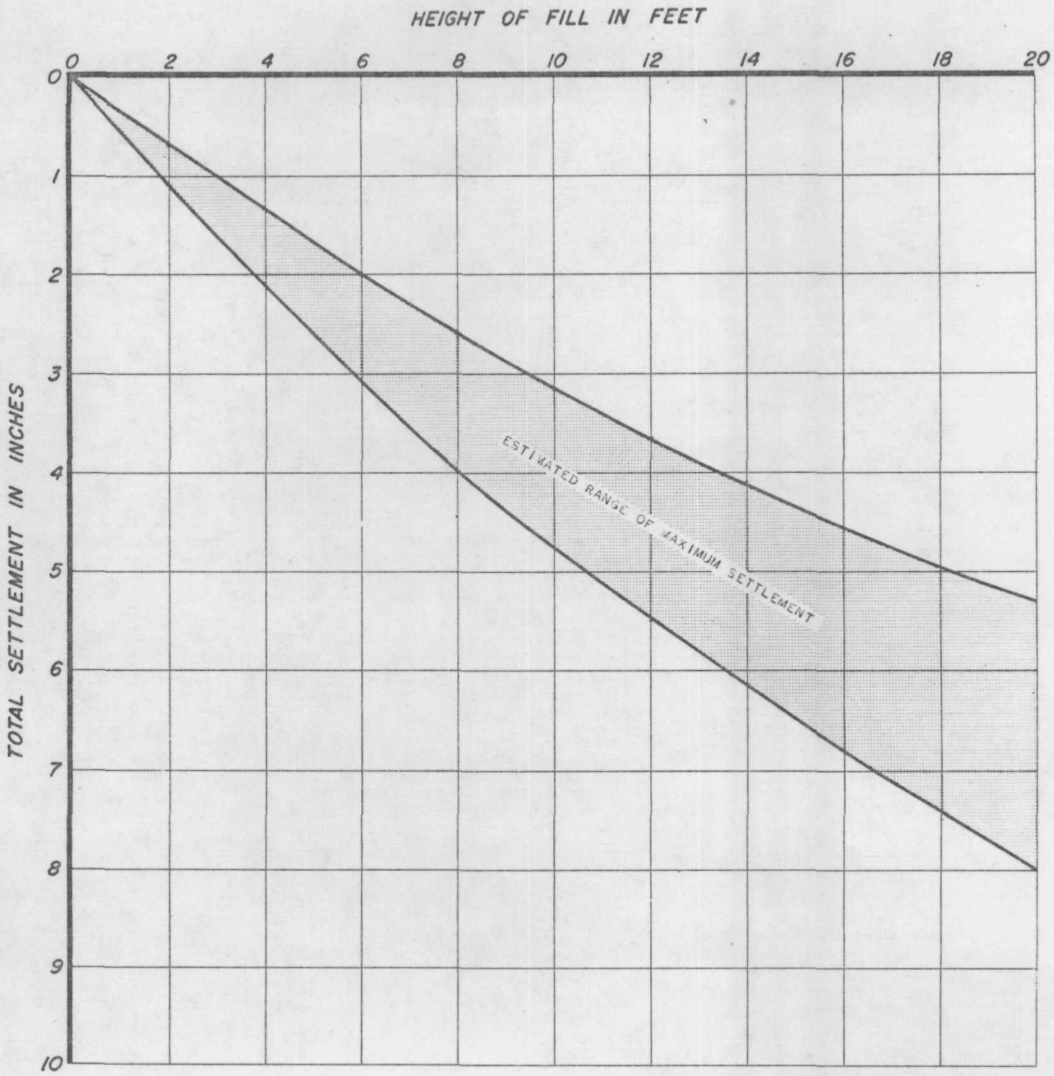
APPLIED EARTH SCIENCES

PLATE 2



NOTE:

SEE TEXT OF REPORT FOR EXPLANATION OF THIS GRAPH.

SETTLEMENT OF AREAL FILL

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Appendix

APPENDIX

FIELD EXPLORATIONS AND LABORATORY TESTS

FIELD EXPLORATIONS

The subsurface conditions at the site were explored by drilling 11 test borings ranging from 46 feet to 82 feet below the ground surface.

Initially, it was planned to drill seven borings (Borings BP-101 through BP-107) in the proposed plant area. When Borings BP-104, BP-105 and BP-106 encountered compressible soils, it was decided to further explore the area immediately north (plant north) of the originally planned plant area. Subsequently, Borings BP-108 through BP-111 were drilled. The locations of the borings are shown on the Plot Plan, Plate 2.

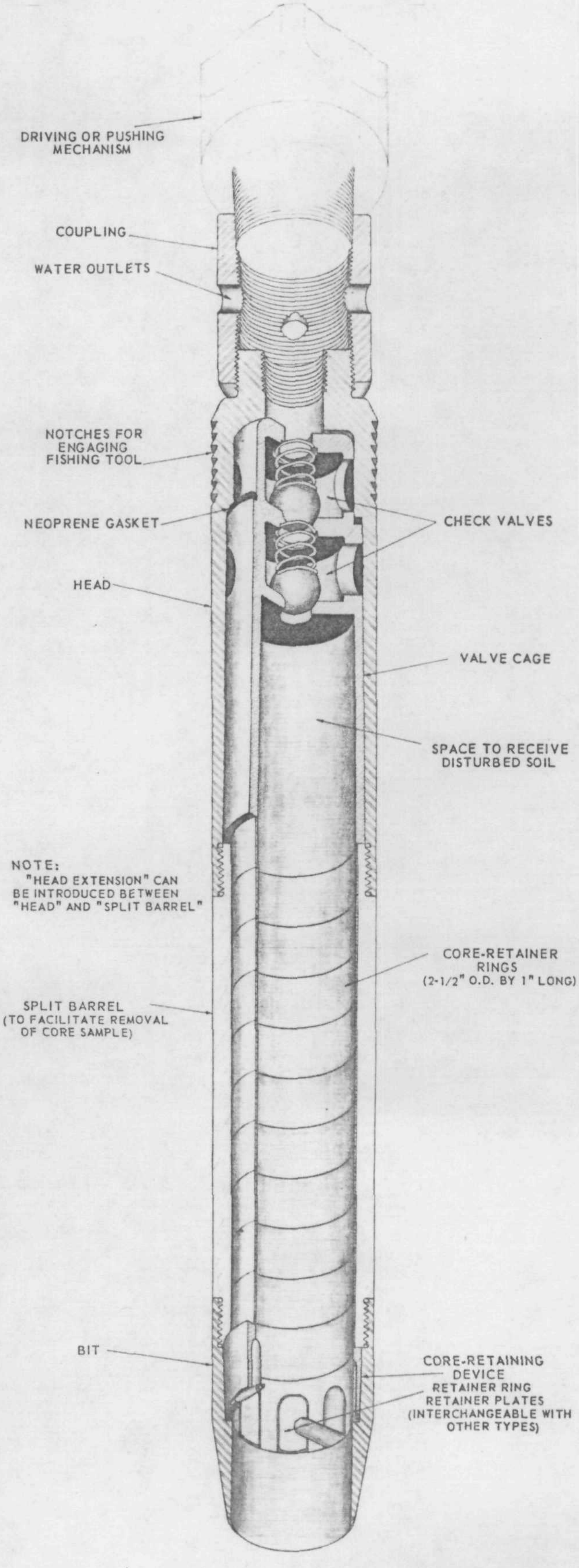
A truck-mounted drill rig was utilized to drill the borings. Augers, having a hollow shaft approximately three and one-half inches in diameter, were used to advance the borings to depths of approximately 45 feet. Below this depth, rotary drilling equipment was used.

The field explorations were performed under the technical direction of a Dames & Moore Soils Engineer. Continuous observations of the soil conditions encountered in the borings were recorded by our Engineer. A graphical presentation of the soils encountered in the borings is shown on the Log of Borings, Plates A-1A through A-1F. The soils were classified in accordance with the Unified Soil Classification System described on Plate A-2. Soil samples extracted from the borings were flown to our New York office for further examination and testing.

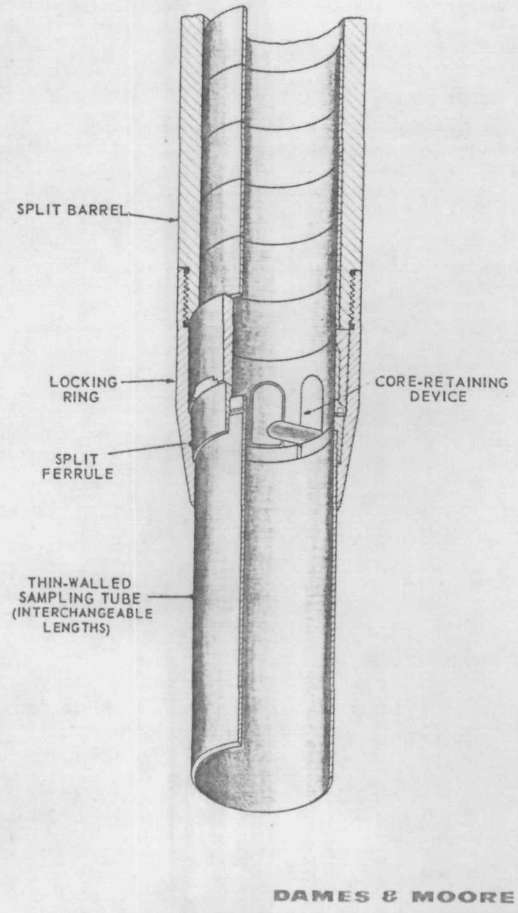
Undisturbed soil samples, suitable for laboratory testing, were extracted from the borings using the Dames & Moore soil sampler illustrated on Page A-2. The sampler is three and one-quarter inches in outside diameter

SOIL SAMPLER TYPE U

FOR SOILS DIFFICULT TO RETAIN IN SAMPLER
U. S. PATENT NO. 2,318,062



ALTERNATE ATTACHMENTS



and approximately two and one-half inches in inside diameter. The soil samples were obtained by driving the sampler with a 140-pound weight falling 30 inches. Where the auger was used, the sampler was inserted through the hollow shaft of the auger, eliminating the necessity of withdrawing the drilling tools from the boring in order to obtain a soil sample. The number of blows required to advance the sampler a distance of one foot is recorded on the Log of Borings under the column labeled "blow count".

Ground surface elevations are presented above the log of each boring. These elevations refer to United States Coast and Geodetic Survey Datum. The borings were located in the field with the assistance of Engineers of The Lummus Company.

The ground water levels observed in the borings at the time of the field explorations are presented on the Log of Borings.

LABORATORY TESTS

General: Selected undisturbed soil samples extracted from the test borings were subjected to appropriate laboratory tests in order to determine the strength and compressibility characteristics of the soils underlying the site and to evaluate their suitability for structural fill. The laboratory tests included:

1) Direct Shear Tests
2) Unconfined Compression Test
3) Consolidation Tests and Confined Compression Tests
4) Relative Density Determinations
5) Moisture-Density Determinations
6) Compaction Test

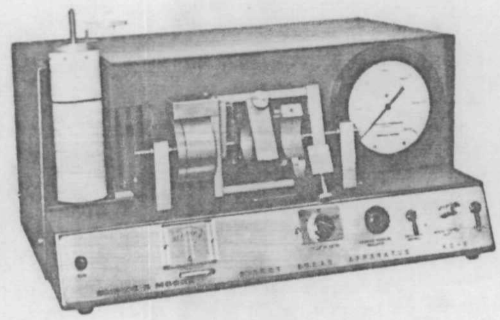
More detailed descriptions of these tests are presented in the following sections.

Direct Shear Tests: Direct shear tests were performed on selected undisturbed samples. These tests were performed in the manner described on Page A-5, Method of Performing Direct Shear and Friction Tests. A load-deflection curve was plotted for each test and the shearing strength of the soil was evaluated directly from this curve. The results of these tests appear on the Log of Borings in the manner described by the Key to Test Data on Plate A-2.

Unconfined Compression Test: An undisturbed sample of clayey silt was subjected to an unconfined compression test. This test was performed in the manner described on Page A-6, Method of Performing Unconfined Compression and Triaxial Compression Tests. The result of this test is presented on the Log of Borings.

Consolidation and Confined Compression Tests: Selected undisturbed soil samples were subjected to consolidation and confined compression tests to evaluate the compressibility characteristics of the various soil strata. The method of performing these tests is described on Page A-7, Method of Performing Consolidation Tests. Consolidation tests are applicable for fine-grained silty and clayey soils where compression under load occurs over an extended time period. In this type of test, the amount of compression and the rate of time required for compression to occur are studied. Confined compression tests are applicable to granular soils, where compression occurs upon application of load and the rate of time required for compression to occur does not require study.

Method Of Performing Direct Shear and Friction Tests



DIRECT SHEAR TESTING
& RECORDING APPARATUS

DIRECT SHEAR TESTS ARE PERFORMED TO DETERMINE THE SHEARING STRENGTHS OF SOILS. FRICTION TESTS ARE PERFORMED TO DETERMINE THE FRICTIONAL RESISTANCES BETWEEN SOILS AND VARIOUS OTHER MATERIALS SUCH AS WOOD, STEEL, OR CONCRETE. THE TESTS ARE PERFORMED IN THE LABORATORY TO SIMULATE ANTICIPATED FIELD CONDITIONS.

EACH SAMPLE IS TESTED WITHIN THREE BRASS RINGS, TWO AND ONE-HALF INCHES IN DIAMETER AND ONE INCH IN LENGTH. UNDISTURBED SAMPLES OF IN-PLACE SOILS ARE TESTED IN RINGS TAKEN FROM THE SAMPLING DEVICE IN WHICH THE SAMPLES WERE OBTAINED. LOOSE SAMPLES OF SOILS TO BE USED IN CONSTRUCTING EARTH FILLS ARE COMPACTED IN RINGS TO PREDETERMINED CONDITIONS AND TESTED.

Direct Shear Tests

A THREE-INCH LENGTH OF THE SAMPLE IS TESTED IN DIRECT DOUBLE SHEAR. A CONSTANT PRESSURE, APPROPRIATE TO THE CONDITIONS OF THE PROBLEM FOR WHICH THE TEST IS BEING PERFORMED, IS APPLIED NORMAL TO THE ENDS OF THE SAMPLE THROUGH POROUS STONES. A SHEARING FAILURE OF THE SAMPLE IS CAUSED BY MOVING THE CENTER RING IN A DIRECTION PERPENDICULAR TO THE AXIS OF THE SAMPLE. TRANSVERSE MOVEMENT OF THE OUTER RINGS IS PREVENTED.

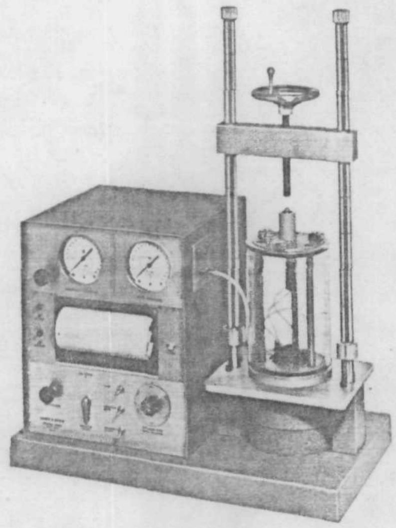
THE SHEARING FAILURE MAY BE ACCOMPLISHED BY APPLYING TO THE CENTER RING EITHER A CONSTANT RATE OF LOAD, A CONSTANT RATE OF DEFLECTION, OR INCREMENTS OF LOAD OR DEFLECTION. IN EACH CASE, THE SHEARING LOAD AND THE DEFLECTIONS IN BOTH THE AXIAL AND TRANSVERSE DIRECTIONS ARE RECORDED AND PLOTTED. THE SHEARING STRENGTH OF THE SOIL IS DETERMINED FROM THE RESULTING LOAD-DEFLECTION CURVES.

Friction Tests

IN ORDER TO DETERMINE THE FRICTIONAL RESISTANCE BETWEEN SOIL AND THE SURFACES OF VARIOUS MATERIALS, THE CENTER RING OF SOIL IN THE DIRECT SHEAR TEST IS REPLACED BY A DISK OF THE MATERIAL TO BE TESTED. THE TEST IS THEN PERFORMED IN THE SAME MANNER AS THE DIRECT SHEAR TEST BY FORCING THE DISK OF MATERIAL FROM THE SOIL SURFACES.

Methods of Performing Unconfined Compression and Triaxial Compression Tests

The shearing strengths of soils are determined from the results of unconfined compression and triaxial compression tests. In triaxial compression tests the test method and the magnitude of the confining pressure are chosen to simulate anticipated field conditions.



TRIAXIAL COMPRESSION TEST UNIT

Unconfined compression and triaxial compression tests are performed on undisturbed or remolded samples of soil approximately six inches in length and two and one-half inches in diameter. The tests are run either strain-controlled or stress-controlled. In a strain-controlled test the sample is subjected to a constant rate of deflection and the resulting stresses are recorded. In a stress-controlled test the sample is subjected to equal increments of load with each increment being maintained until an equilibrium condition with respect to strain is achieved.

Yield, peak, or ultimate stresses are determined from the stress-strain plot for each sample and the principal stresses are evaluated. The principal stresses are plotted on a Mohr's circle diagram to determine the shearing strength of the soil type being tested.

Unconfined compression tests can be performed only on samples with sufficient cohesion so that the soil will stand as an unsupported cylinder. These tests may be run at natural moisture content or on artificially saturated soils.

In a triaxial compression test the sample is encased in a rubber membrane, placed in a test chamber, and subjected to a confining pressure throughout the duration of the test. Normally, this confining pressure is maintained at a constant level, although for special tests it may be varied in relation to the measured stresses. Triaxial compression tests may be run on soils at field moisture content or on artificially saturated samples. The tests are performed in one of the following ways:

<u>Unconsolidated-Undrained:</u> The confining pressure is imposed on the sample at the start of the test. No drainage is permitted and the stresses which are measured represent the sum of the intergranular stresses and pore water pressures.

<u>Consolidated-Undrained:</u> The sample is allowed to consolidate fully under the applied confining pressure prior to the start of the test. The volume change is determined by measuring the water and/or air expelled during consolidation. No drainage is permitted during the test and the stresses which are measured are the same as for the unconsolidated-undrained test.

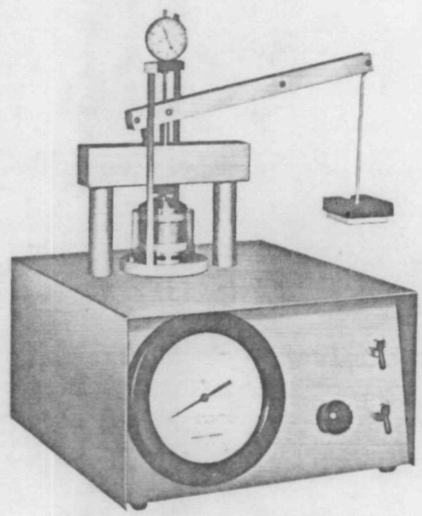
<u>Drained:</u> The intergranular stresses in a sample may be measured by performing a drained, or slow, test. In this test the sample is fully saturated and consolidated prior to the start of the test. During the test, drainage is permitted and the test is performed at a slow enough rate to prevent the buildup of pore water pressures. The resulting stresses which are measured represent only the intergranular stresses. These tests are usually performed on samples of generally non-cohesive soils, although the test procedure is applicable to cohesive soils if a sufficiently slow test rate is used.

An alternate means of obtaining the data resulting from the drained test is to perform an undrained test in which special equipment is used to measure the pore water pressures. The differences between the total stresses and the pore water pressures measured are the intergranular stresses.

Method Of Performing Consolidation Tests

Consolidation tests are performed to evaluate the volume changes of soils subjected to increased loads. Time-consolidation and pressure-consolidation curves may be plotted from the data obtained in the tests. Engineering analyses based on these curves permit estimates to be made of the probable magnitude and rate of settlement of the tested soils under applied loads.

Each sample is tested within brass rings two and one-half inches in diameter and one inch in length. Undisturbed samples of in-place soils are tested in rings taken from the sampling device in which the samples were obtained. Loose samples of soils to be used in constructing earth fills are compacted in rings to predetermined conditions and tested.



DEAD LOAD-PNEUMATIC CONSOLIDOMETER

In testing, the sample is rigidly confined laterally by the brass ring. Axial loads are transmitted to the ends of the sample by porous disks. The disks allow drainage of the loaded sample. The axial compression or expansion of the sample is measured by a micrometer dial indicator at appropriate time intervals after each load increment is applied. Each load is ordinarily twice the preceding load. The increments are selected to obtain consolidation data representing the field loading conditions for which the test is being performed. Each load increment is allowed to act over an interval of time dependent on the type and extent of the soil in the field.

The results of these tests appear on Plate A-3A, Consolidation Test Data and Plate A-3B, Confined Compression Test Data.

Relative Density Tests: Relative density tests were performed on samples of the underlying sandy soils to provide additional data for use in evaluating the relative compactness of the sand stratum in different areas of the site. The relative density tests were performed on oven-dried samples. The maximum density of each sample was obtained by compacting the soil in thin layers in a two and one-half inch diameter cylinder, two inches in height, with the tamping action from a "vibro tool" fitted with a vibrating tamping foot about one and one-half inches in diameter. The minimum density was obtained by slowly pouring the soil into the same cylinder utilizing a funnel. The relative density was then computed by using a formula comparing the field density of the sample with the maximum and minimum densities. The results of the relative density determinations are tabulated below:

BORING	DEPTH (feet)	MAXIMUM DRY DENSITY (pounds per cubic foot)	MINIMUM DRY DENSITY (pounds per cubic foot)	FIELD DRY DENSITY (pounds per cubic foot)	RELATIVE DENSITY (percent)
BP-103	20	104	91	103	94
BP-103	25	108	87	99	64
BP-105	9	109	85	98	60
BP-107	10	107	92	96	30
BP-108	5	104	87	96	58
BP-109	10	108	92	98	43

Moisture-Density Determinations: The moisture content and dry density were determined for each soil sample subjected to a strength, confined compression or consolidation test. The moisture content and dry density of other samples were also determined for correlation purposes. Results of these tests are presented on the Log of Borings.

Compaction Test: A compaction test was performed on a bulk sample of the brown firm sand extracted from Boring BP-107 in accordance with the method described on Page A-10, Method of Performing Compaction Tests (Modified AASHO Method). The results of this test are presented on Plate A-4, Compaction Test Data.

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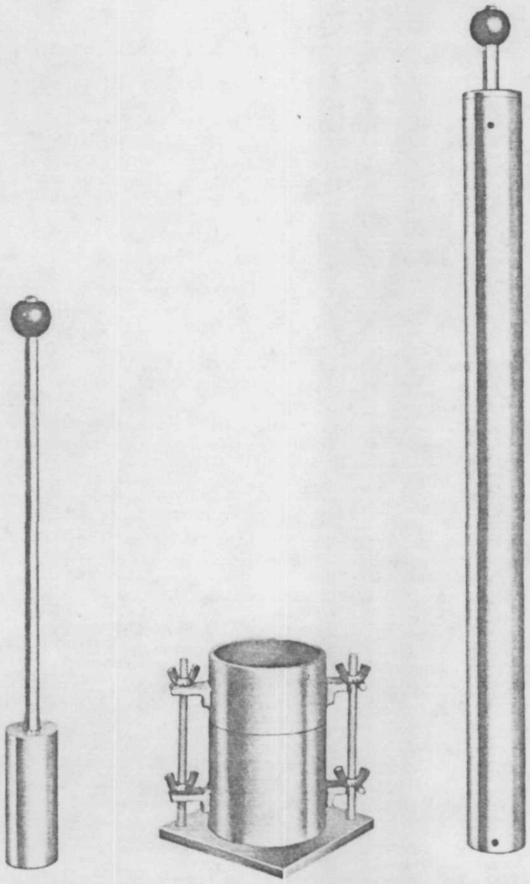
The following Plates are attached and complete this Appendix:

Plate A-1A	-	Log of Borings (Borings BP-101 and 102)
Plate A-1B	-	Log of Boring (Boring BP-103)
Plate A-1C	-	Log of Borings (Borings BP-104 and 105)
Plate A-1D	-	Log of Borings (Borings BP-106 and 107)
Plate A-1E	-	Log of Borings (Borings BP-108 and 109)
Plate A-1F	-	Log of Borings (Borings BP-110 and 111)
Plate A-2	-	Unified Soil Classification System and Key to Test Data
Plate A-3A	-	Consolidation Test Data
Plate A-3B	-	Confined Compression Test Data
Plate A-4	-	Compaction Test Data

METHOD OF PERFORMING COMPACTION TESTS
(STANDARD AND MODIFIED A.A.S.H.O. METHODS)

IT HAS BEEN ESTABLISHED THAT WHEN COMPACTING EFFORT IS HELD CONSTANT, THE DENSITY OF A ROLLED EARTH FILL INCREASES WITH ADDED MOISTURE UNTIL A MAXIMUM DRY DENSITY IS OBTAINED AT A MOISTURE CONTENT TERMED THE "OPTIMUM MOISTURE CONTENT," AFTER WHICH THE DRY DENSITY DECREASES. THE COMPACTION CURVE SHOWING THE RELATIONSHIP BETWEEN DENSITY AND MOISTURE CONTENT FOR A SPECIFIC COMPACTING EFFORT IS DETERMINED BY EXPERIMENTAL METHODS. TWO COMMONLY USED METHODS ARE DESCRIBED IN THE FOLLOWING PARAGRAPHS.

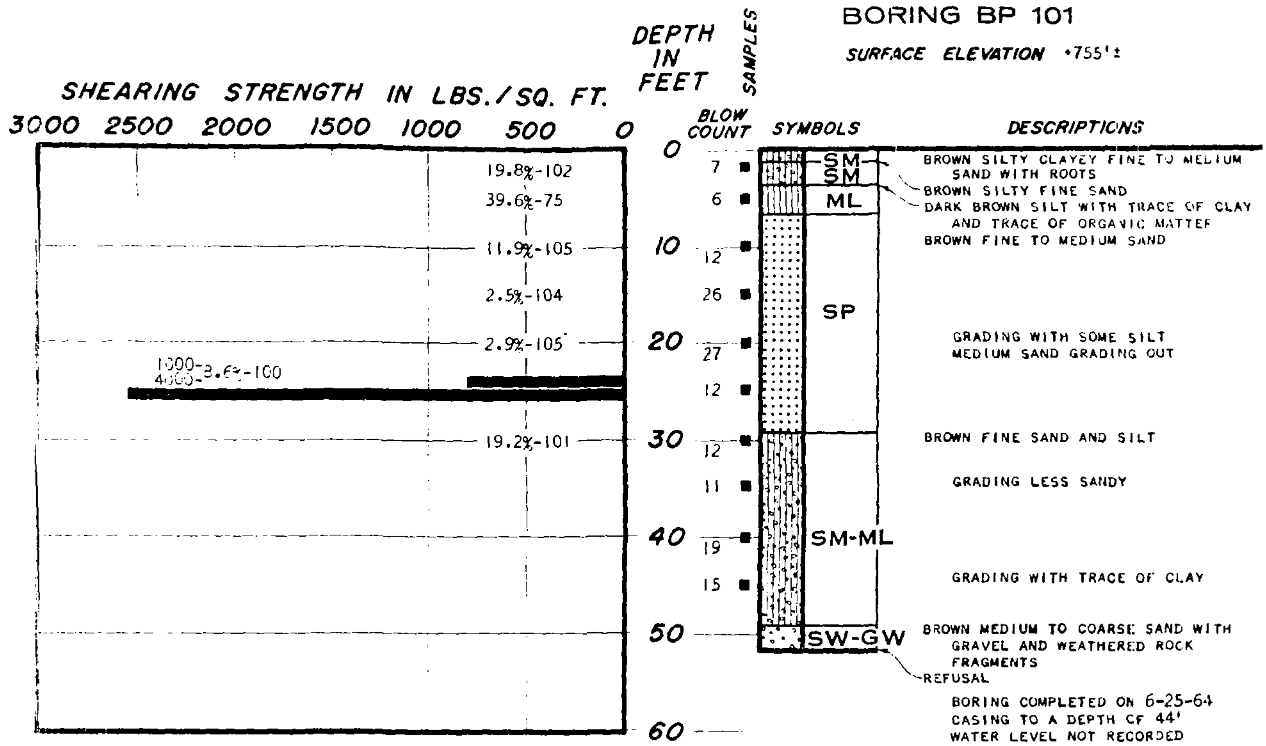
FOR THE "STANDARD A.A.S.H.O." (A.S.T.M. D698-58T & A.A.S.H.O. T99-57) METHOD OF COMPACTION A PORTION OF THE SOIL SAMPLE PASSING THE NO. 4 SIEVE IS COMPACTED AT A SPECIFIC MOISTURE CONTENT IN THREE EQUAL LAYERS IN A STANDARD COMPACTION CYLINDER HAVING A VOLUME OF 1/30 CUBIC FOOT, USING TWENTY-FIVE 12-INCH BLOWS OF A STANDARD 5-1/2 POUND RAMMER TO COMPACT EACH LAYER.

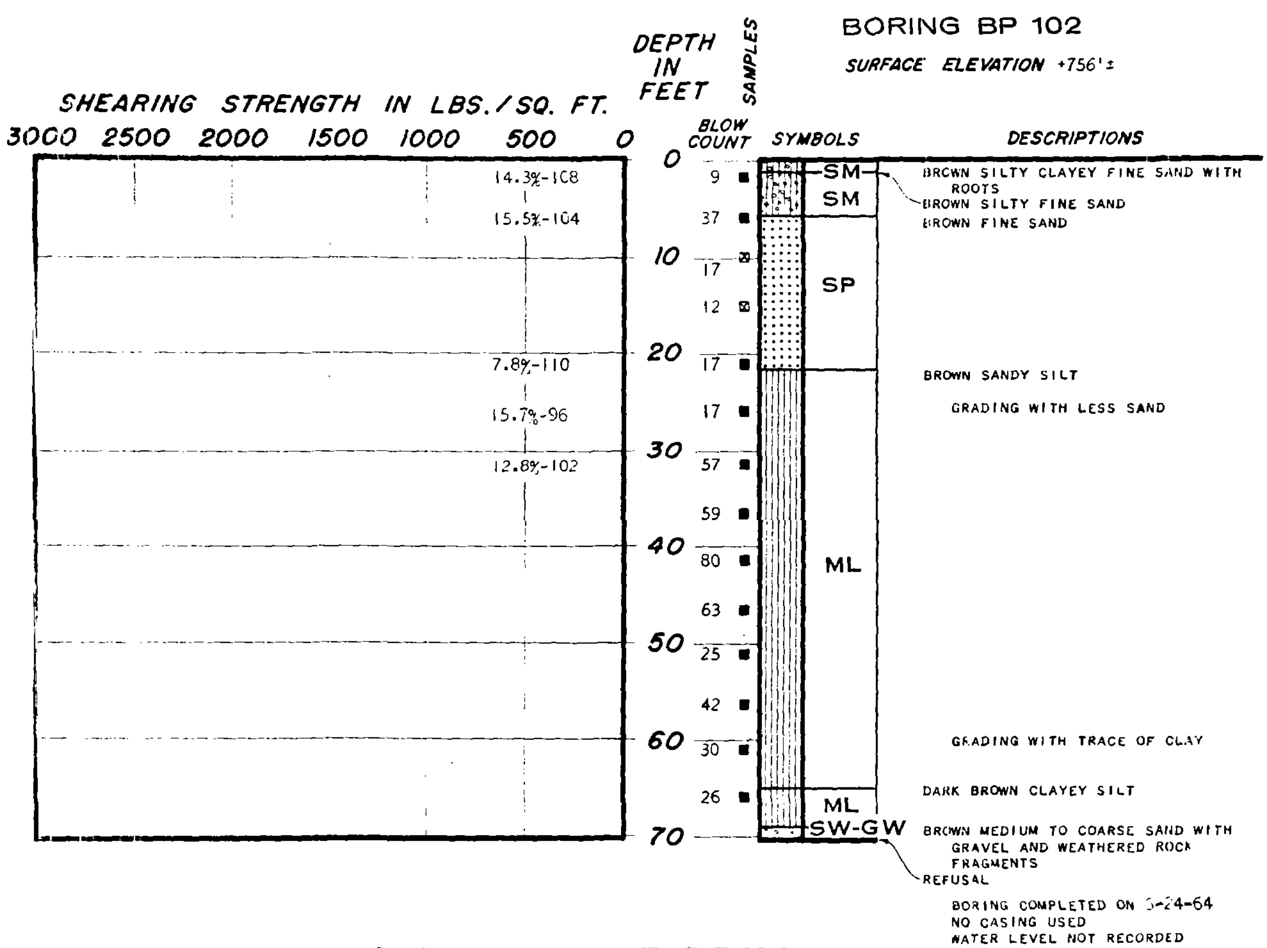


SOME APPARATUS FOR PERFORMING COMPACTION TESTS
Shows, from left to right, 5-1/2 pound rammer (sleeve controlling 12" height of drop removed), 1/30 cubic-foot cylinder with removable collar and base plate, and 10 pound rammer within sleeve.

IN THE "MODIFIED A.A.S.H.O." (A.S.T.M. D-1557-58T & A.A.S.H.O. T 180-57) METHOD OF COMPACTION A PORTION OF THE SOIL SAMPLE PASSING THE NO. 4 SIEVE IS COMPACTED AT A SPECIFIC MOISTURE CONTENT IN FIVE EQUAL LAYERS IN A STANDARD COMPACTION CYLINDER HAVING A VOLUME OF 1/30 CUBIC FOOT, USING TWENTY-FIVE 18-INCH BLOWS OF A 10-POUND RAMMER TO COMPACT EACH LAYER. SEVERAL VARIATIONS OF THESE COMPACTION TESTING METHODS ARE OFTEN USED AND THESE ARE DESCRIBED IN A.A.S.H.O. & A.S.T.M. SPECIFICATIONS.

FOR BOTH METHODS, THE WET DENSITY OF THE COMPACTED SAMPLE IS DETERMINED BY WEIGHING THE KNOWN VOLUME OF SOIL; THE MOISTURE CONTENT, BY MEASURING THE LOSS OF WEIGHT OF A PORTION OF THE SAMPLE WHEN OVEN DRIED; AND THE DRY DENSITY, BY COMPUTING IT FROM THE WET DENSITY AND MOISTURE CONTENT. A SERIES OF SUCH COMPACTIONS IS PERFORMED AT INCREASING MOISTURE CONTENTS UNTIL A SUFFICIENT NUMBER OF POINTS DEFINING THE MOISTURE-DENSITY RELATIONSHIP HAVE BEEN OBTAINED TO PERMIT THE PLOTTING OF THE COMPACTION CURVE. THE MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT FOR THE PARTICULAR COMPACTING EFFORT ARE DETERMINED FROM THE COMPACTION CURVE.





LOG OF BORINGS

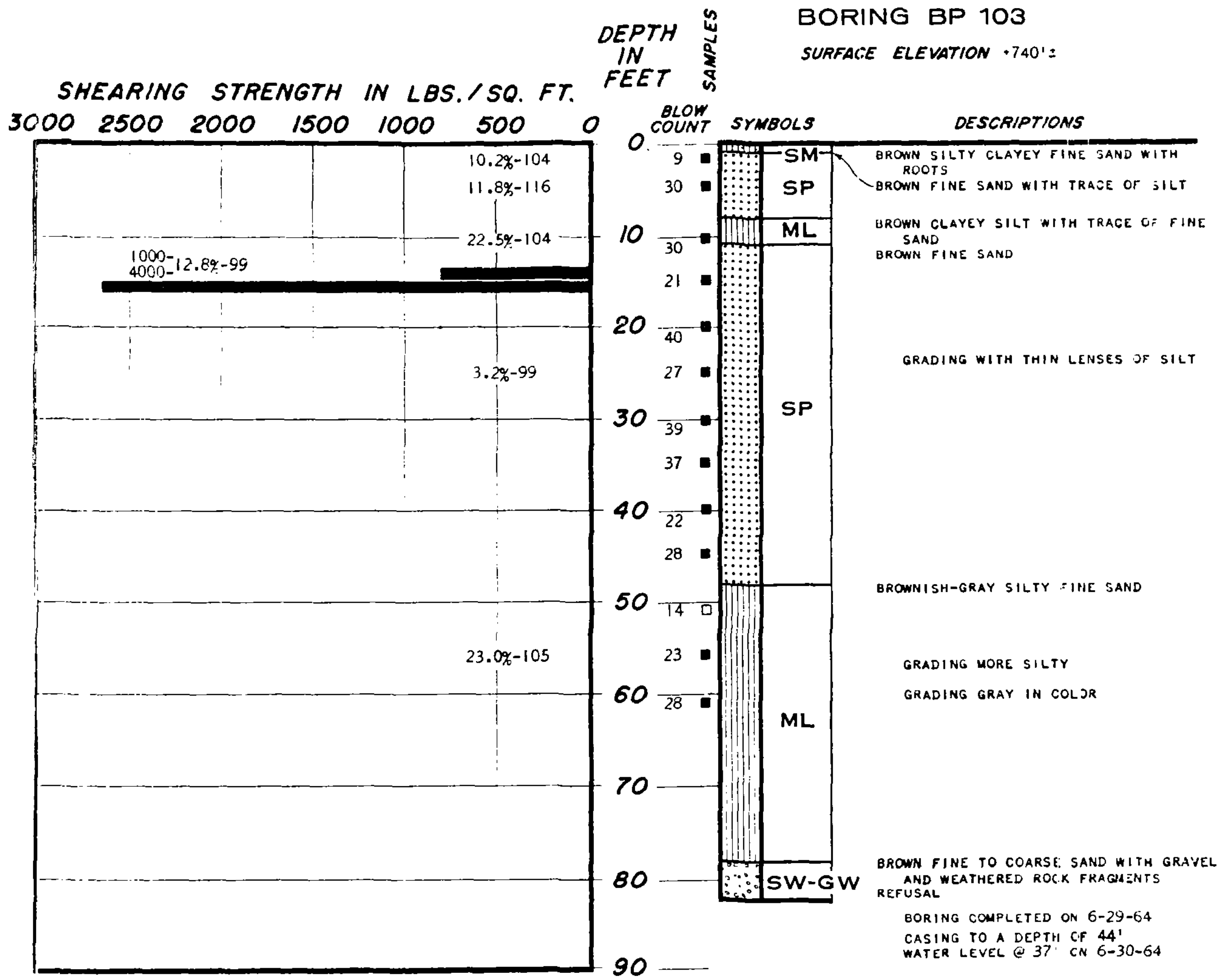
NOTES:

1) FIGURES UNDER THE COLUMN LABELED "BLOW COUNT" REFER TO THE NUMBER OF BLOWS REQUIRED TO DRIVE THE SAMPLER A DISTANCE OF ONE FOOT WITH A 140 POUND WEIGHT FALLING 30 INCHES. THE DAMES & MOORE SAMPLER IS 3¼" O.D. AND 2½" I.D.

2) SURFACE ELEVATIONS REFER TO USCGS DATUM.

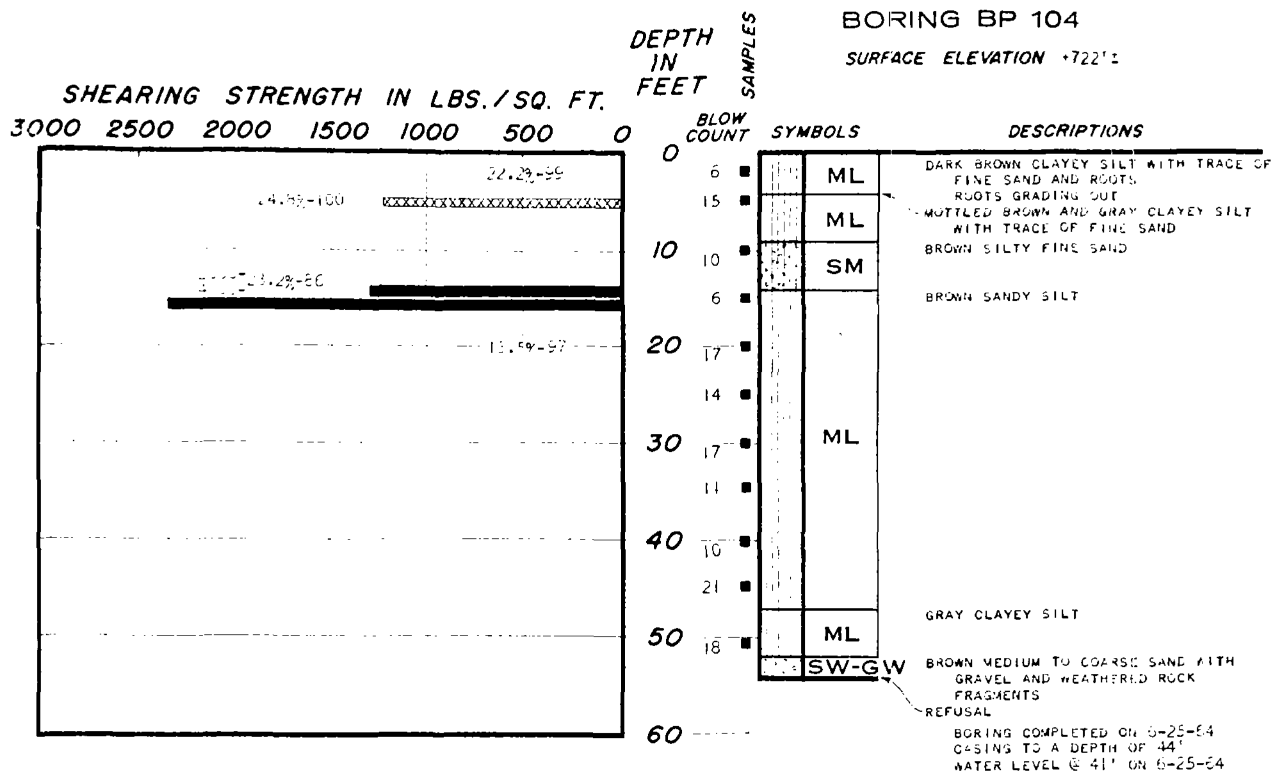
DAMES & MOORE
APPLIED EARTH SCIENCES

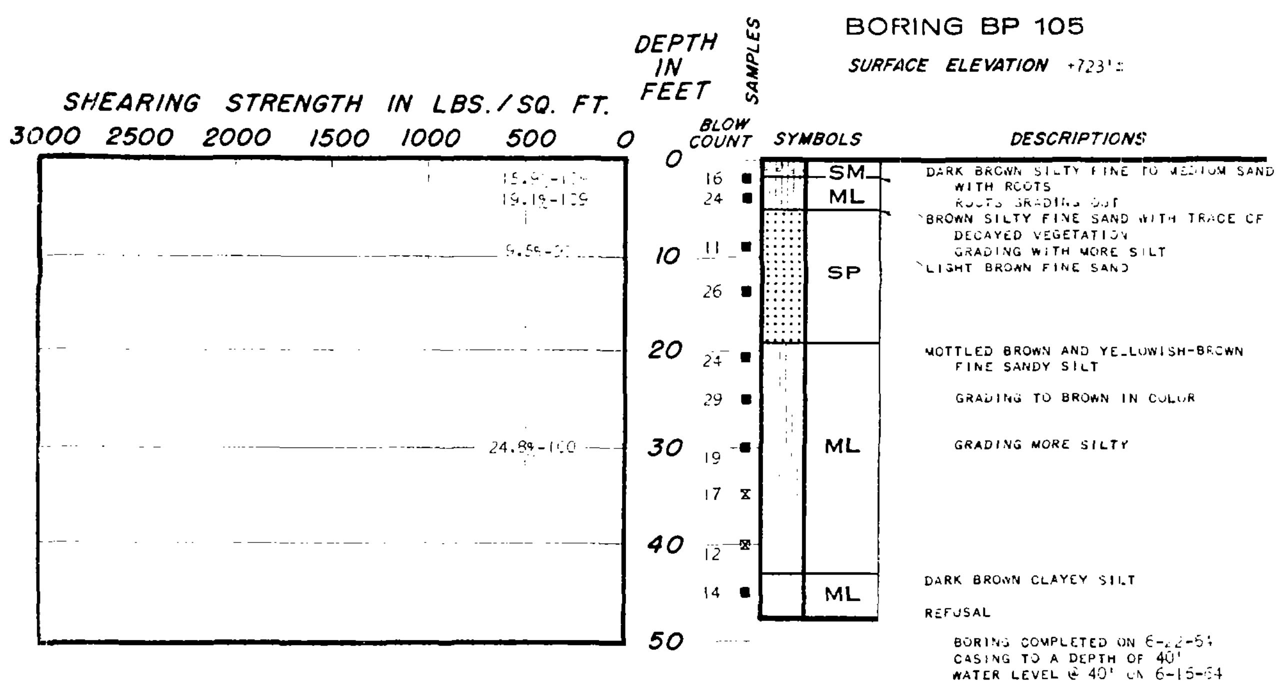
PLATE A-1A



LOG OF BORING

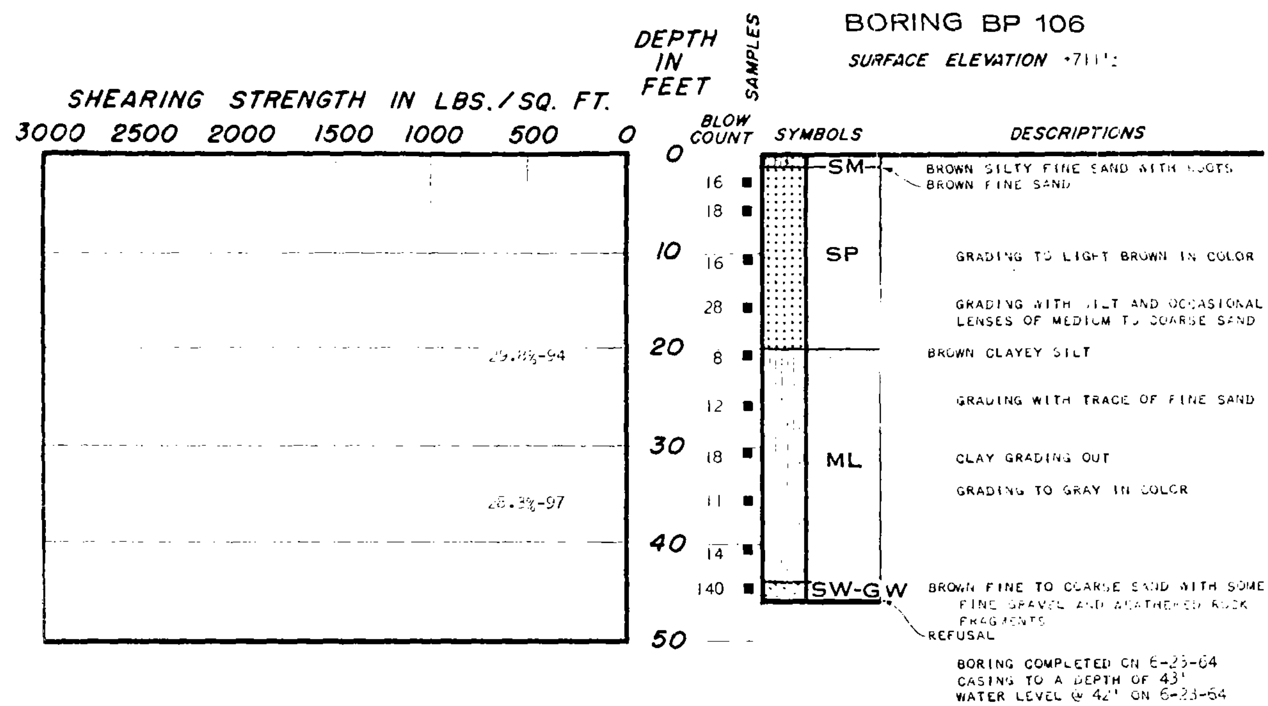
DAMES & MOORE
APPLIED EARTH SCIENCES

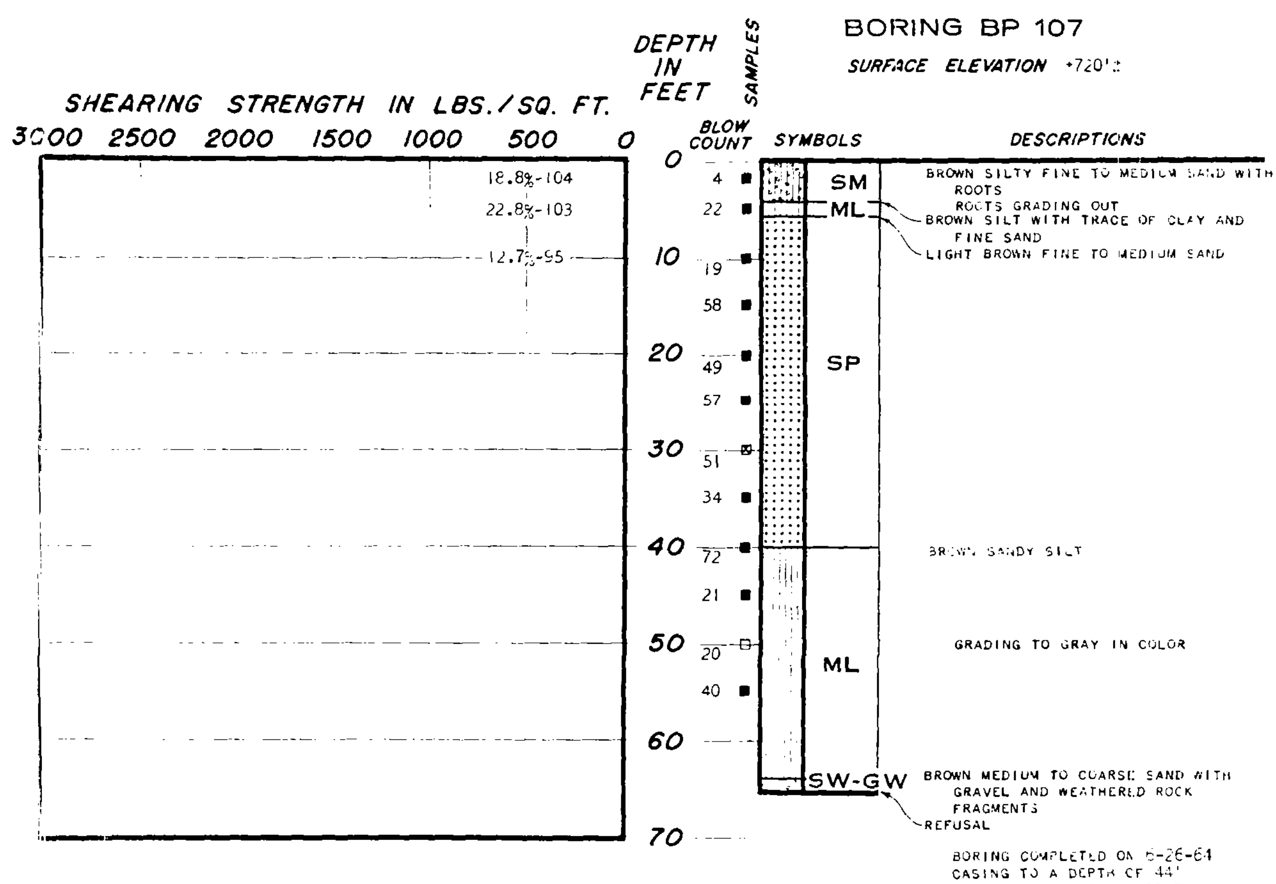




LOG OF BORINGS

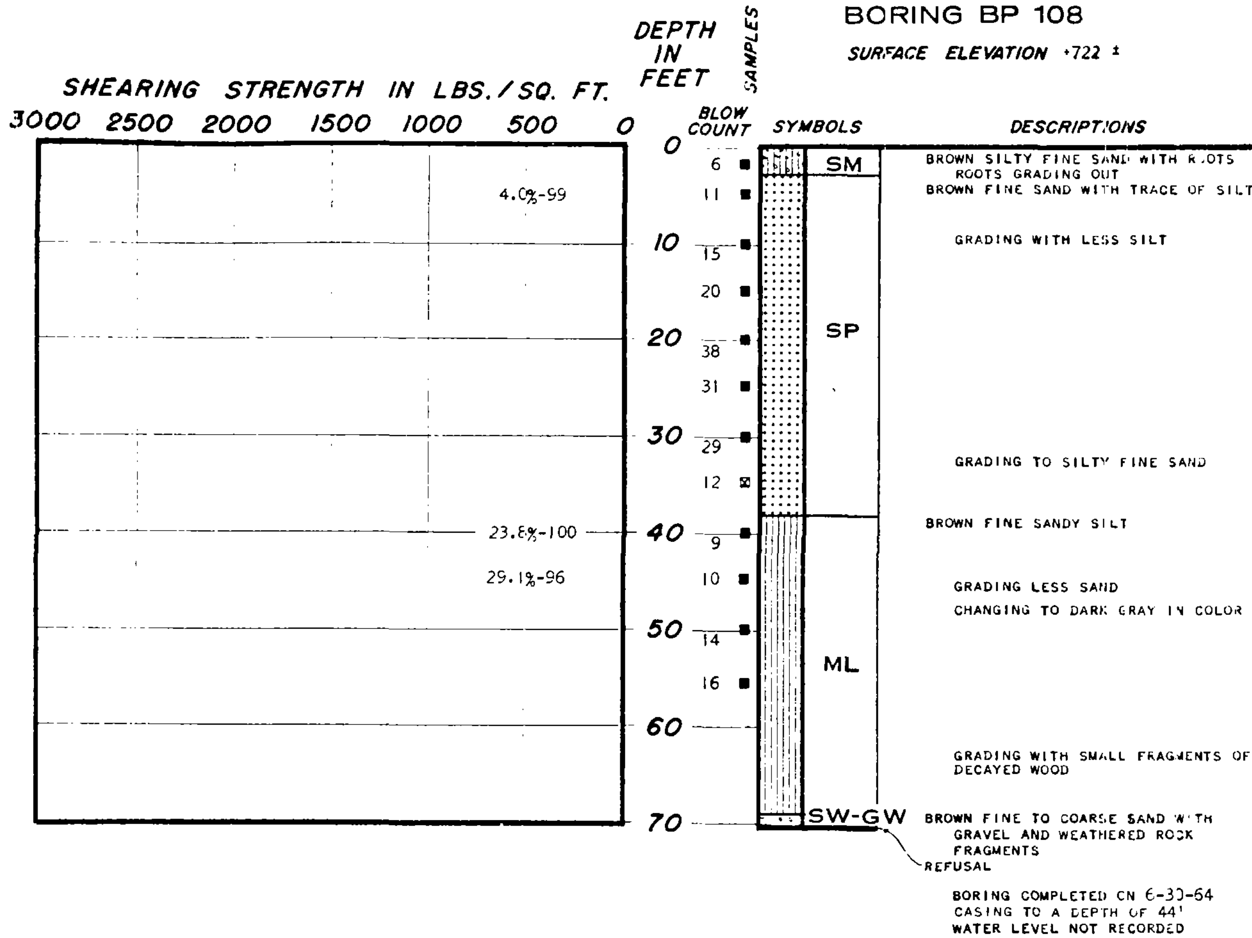
DAMES & MOORE
APPLIED EARTH SCIENCES

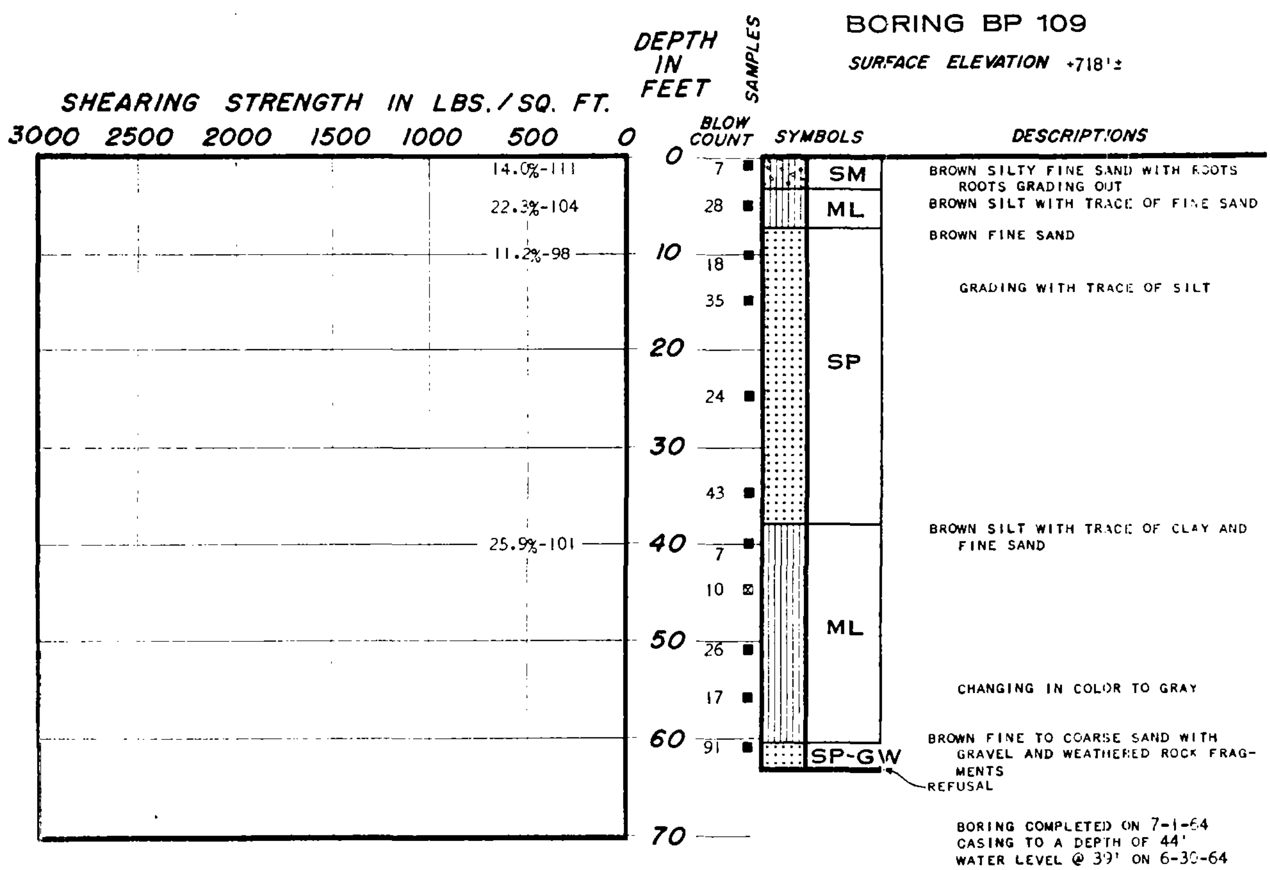




LOG OF BORINGS

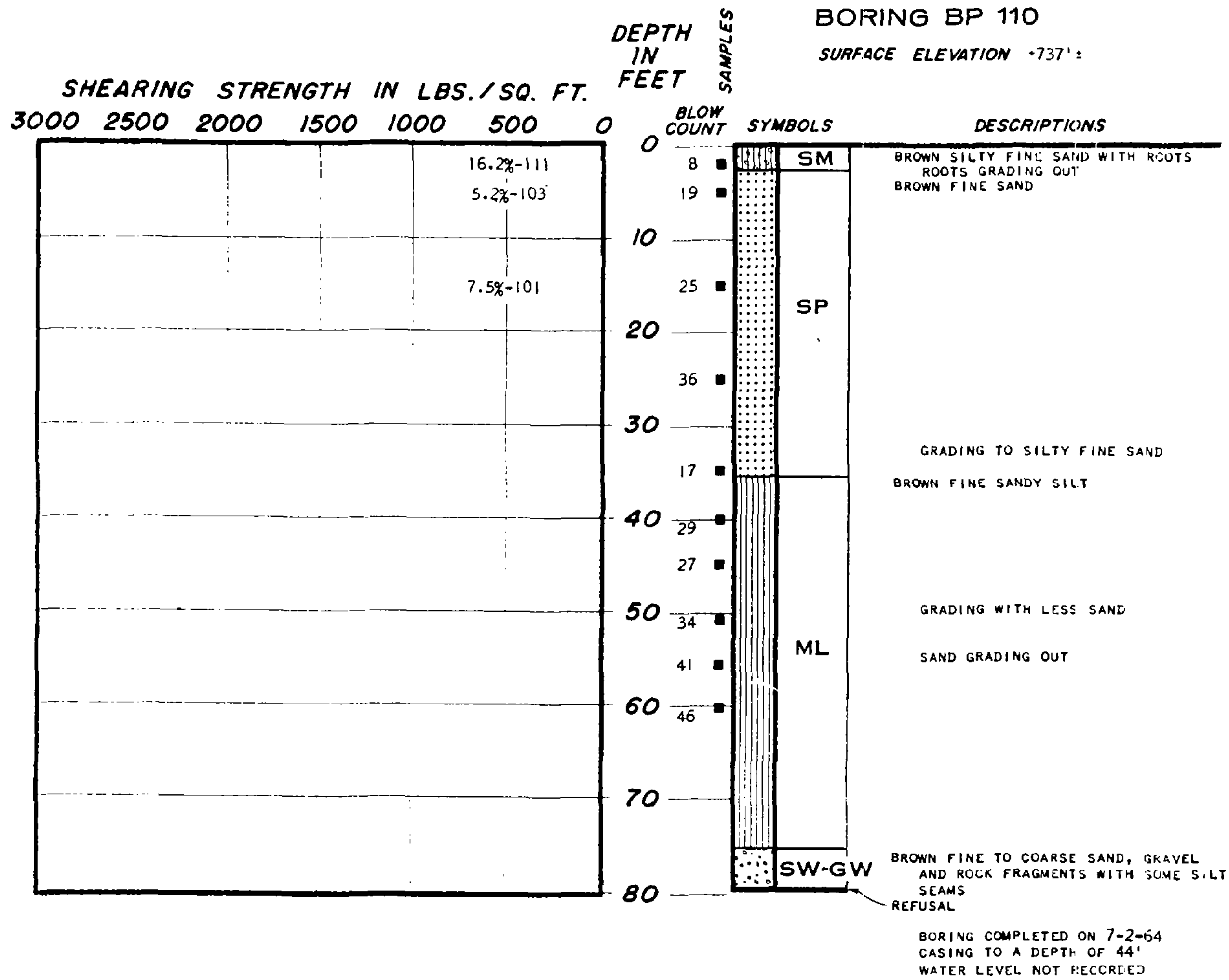
DAMES & MOORE
APPLIED EARTH SCIENCES

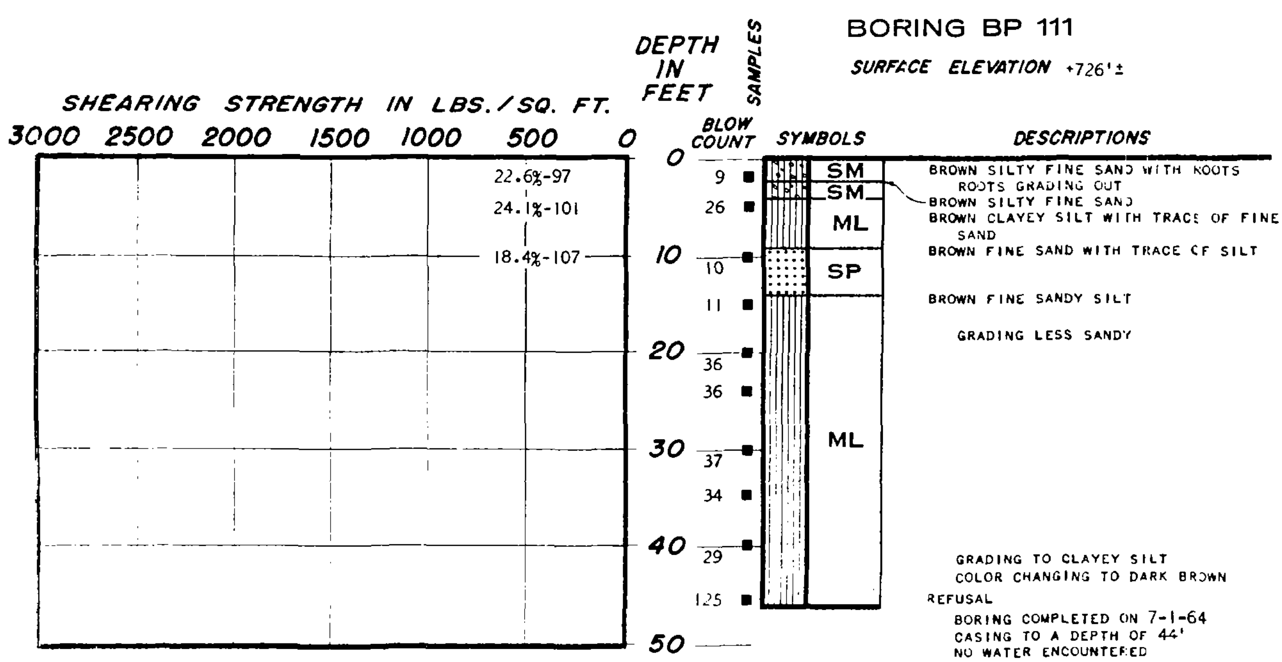




LOG OF BORINGS

DAMES & MOORE
APPLIED EARTH SCIENCES





LOG OF BORINGS

DAMES & MOORE

APPLIED EARTH SCIENCES

KEY TO TEST DATA

UNCONFINED COMPRESSION TESTS

TRIAXIAL COMPRESSION TESTS

ROCK COMPRESSION TESTS

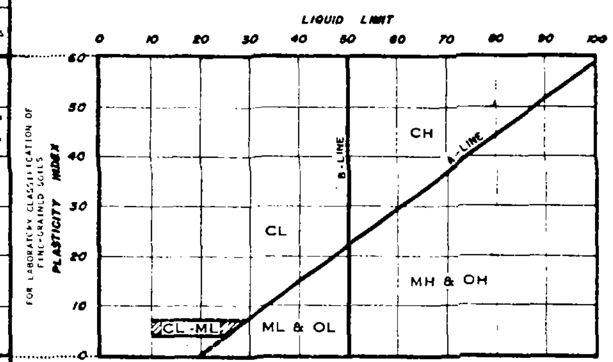
- ■ INDICATES DEPTH OF UNDISTURBED SAMPLE
- ☒ INDICATES DEPTH OF DISTURBED SAMPLE
- INDICATES DEPTH OF SAMPLING ATTEMPT WITH NO RECOVERY
- INDICATES DEPTH OF SPLIT-SPOON SAMPLE
- I INDICATES DEPTH AND LENGTH OF CORING RUN

KEY TO SAMPLES

MAJOR DIVISIONS			GRAPH SYMBOL	LETTER SYMBOL	TYPICAL DESCRIPTIONS
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	CLEAN GRAVELS (LITTLE OR NO FINES)		GW	[illegible] NO FINES
				GP	[illegible]
MORE THAN 50% OF MATERIAL IS LARGER THAN NO. 200 SIEVE SIZE	MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)		GM	SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
				GC	CLAYEY GRAVELS, GRAVEL-SAND-CLAY MIXTURES
	SAND AND SANDY SOILS	CLEAN SAND (LITTLE OR NO FINES)		SW	WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
				SP	POORLY-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
	MORE THAN 50% OF COARSE FRACTION PASSING NO. 4 SIEVE	SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)		SM	SILTY SANDS, SAND-SILT MIXTURES
				SC	CLAYEY SANDS, SAND-CLAY MIXTURES
FINE GRAINED SOILS	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 50		ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
				CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
				OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
MORE THAN 50% OF MATERIAL IS SMALLER THAN NO. 200 SIEVE SIZE	SILTS AND CLAYS	LIQUID LIMIT GREATER THAN 50		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SAND OR SILTY SOILS
				CH	INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS
				OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
HIGHLY ORGANIC SOILS				PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS

NOTE: DUAL SYMBOLS ARE USED TO INDICATE BORDERLINE SOIL CLASSIFICATIONS.

SOIL CLASSIFICATION CHART

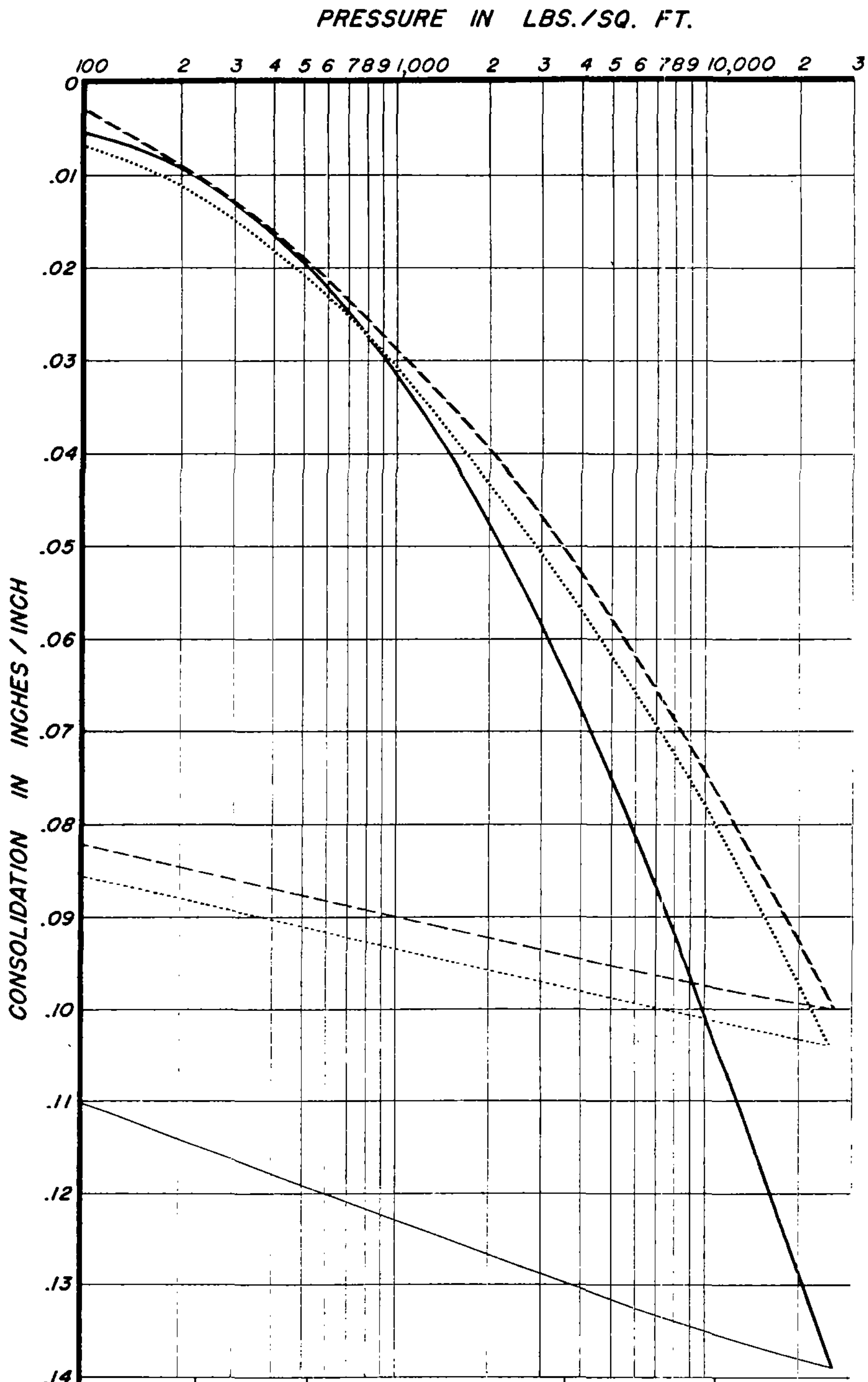


PLASTICITY CHART

UNIFIED SOIL CLASSIFICATION SYSTEM

DAMES & MOORE

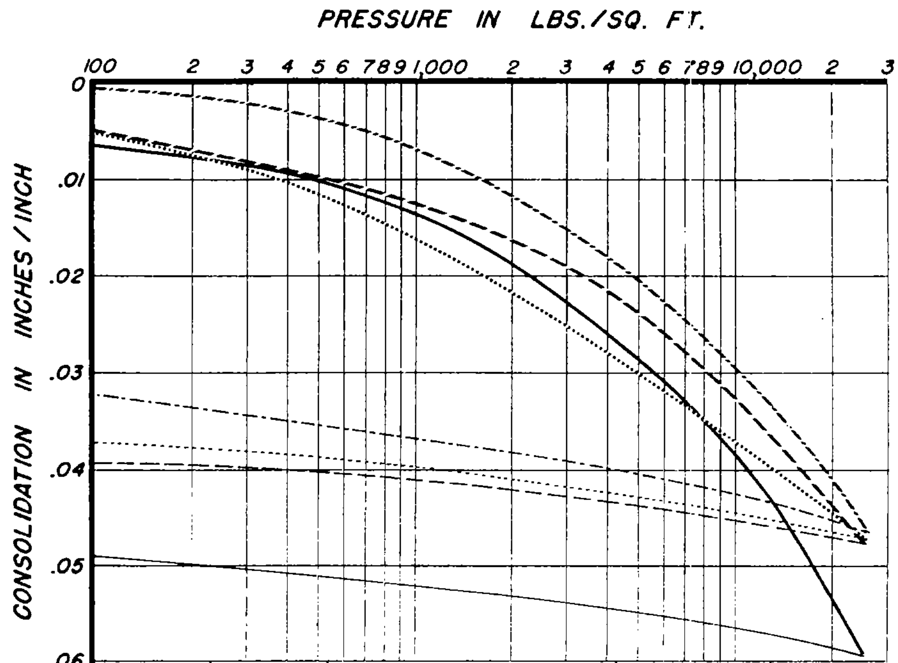
PLATE A-2



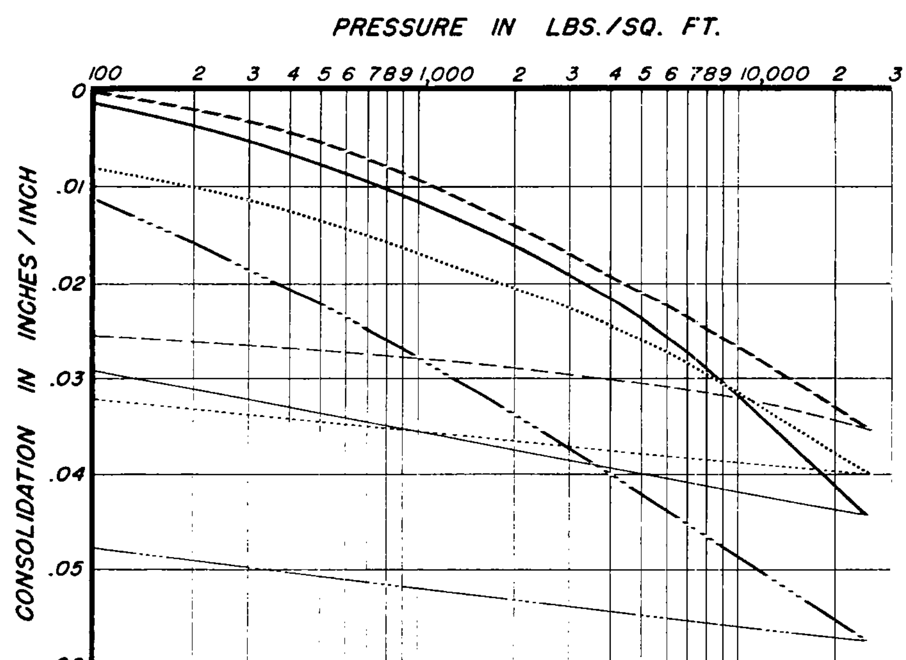
LINE SYMBOL	BORING NO. AND DEPTH	SOIL TYPE	FIELD MOISTURE CONTENT IN % OF DRY WEIGHT	FIELD DRY DENSITY IN LBS./CU.FT.
———	106 @ 21	BROWN CLAYEY SILT	29.8	94
········	106 @ 36'	GRAY SANDY SILT	28.3	97
– – – –	108 @ 45'	BROWN FINE SANDY SILT	29.1	96

CONSOLIDATION TEST DATA

DAMES & MOORE
APPLIED EARTH SCIENCES



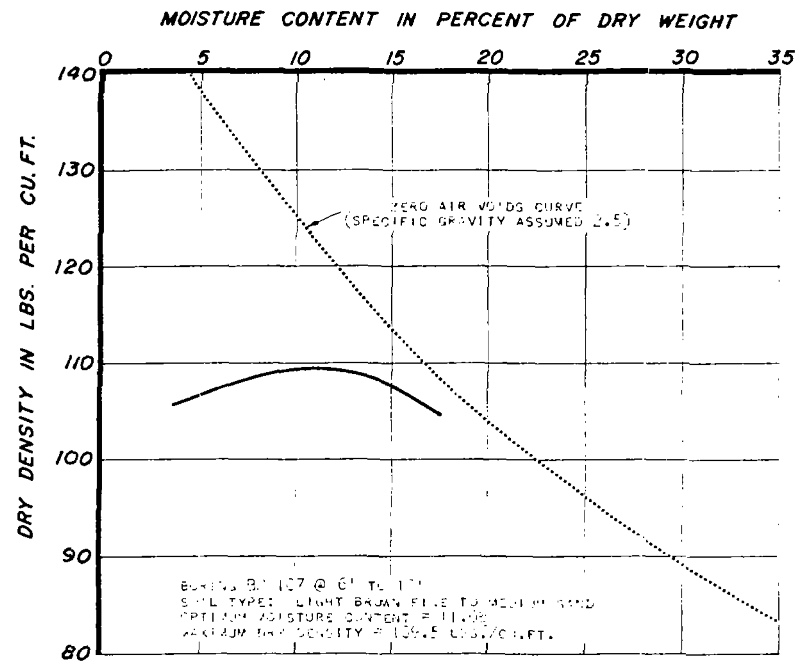
LINE SYMBOL	BORING NO. AND DEPTH	SOIL TYPE	FIELD MOISTURE CONTENT IN % OF DRY WEIGHT	FIELD DRY DENSITY IN LBS./CU.FT.
	102 @ 26'	BROWN SANDY SILT	15.9	96
	105 @ 1 3/4'	BROAN SILTY FINE SAND WITH TRACE OF DECAYED VEGETATION	15.9	109
	105 @ 9'	LIGHT BROWN FINE SAND	[illegible].5	98
	108 @ 5'	BROWN FINE SAND WITH TRACE OF SILT	4.0	99



LINE SYMBOL	BORING NO. AND DEPTH	SOIL TYPE	FIELD MOISTURE CONTENT IN % OF DRY WEIGHT	FIELD DRY DENSITY IN LBS./CU.FT.
	103 @ 25'	BROWN FINE SAND	3.2	99
	104 @ 20'	BROWN SANDY SILT	13.5	97
	107 @ 10'	LIGHT BROWN FINE TO MEDIUM SAND	12.7	95
	109 @ 10'	BROWN FINE SAND	11.2	98

CONFINED COMPRESSION DATA

DAMES & MOORE
APPLIED EARTH SCIENCES



NOTE:

THIS COMPACTION TEST WAS PERFORMED IN ACCORDANCE WITH THE MODIFIED AASHO METHOD OF COMPACTION.

COMPACTION TEST DATA

DAMES & MOORE
APPLIED EARTH SCIENCES